APPENDIX B

TRANSPORTATION ANALYSIS
FOR
URANIUM MANAGEMENT PROGRAMMATIC
ENVIRONMENTAL ASSESSMENT

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ACRONYMS

DOE	U.S. Department of Energy
DU	depleted uranium
ICRP	International Commission on Radiological Protection
INEEL	Idaho National Engineering and Environmental Laboratory
LCF	latent cancer fatality
LEU	low-enriched uranium
NU	normal uranium
PGDP	Paducah Gaseous Diffusion Plant
PORTS	Portsmouth Gaseous Diffusion Plant
SRS	Savannah River Site
TRAGIS	Transportation Routing Analysis Geographic Information System
vph	vehicles per hour

APPENDIX B
TRANSPORTATION ANALYSIS FOR URANIUM MANAGEMENT PROGRAMMATIC ENVIRONMENTAL ASSESSMENT

B.1 PURPOSE

The purpose of this calculation package is to provide details of the risk analysis of transporting normal uranium (NU), depleted uranium (DU), and low-enriched uranium (LEU) to and from a number of sites.

B.2 METHOD

Routes were calculated for highway from the 155 origin sites to 11 alternate destinations in the United States:

1. the nearest U.S. Department of Energy (DOE) consolidation site;
2. Savannah River Site (SRS);
3. Portsmouth Gaseous Diffusion Plant (PORTS);
4. Paducah Gaseous Diffusion Plant (PGDP);
5. Idaho National Engineering and Environmental Laboratory (INEEL);
6. Oak Ridge National Laboratory and other Oak Ridge facilities;
7. a "western commercial site," for which Envirocare in Utah was selected;
8. an "eastern commercial site," for which Barnwell in South Carolina was selected;
9. the nearest DOE consolidation site when consolidating by material form;
10. PORTS or INEEL, whichever is closer to the origin site; and
11. Envirocare or Barnwell, whichever is closer to the origin site.

Rail routes were calculated where appropriate. Route distances and population densities for rural, suburban, and urban route segments were calculated using the Transportation Routing Analysis Geographic Information System (TRAGIS).[1]

Two modal options were analyzed:

1. all shipment by truck, and

2. shipment by rail where rail was appropriate, and all other shipment by truck (this is called the "truck/rail" option).

Public and occupational doses for incident-free transportation and dose risks for transportation accidents were estimated by calculating unit risk factors using RADTRAN 5[2] (a transportation risk

[1]TRAGIS is a routing analysis tool combining graphical interfaces with an extensive highway, rail, and waterway database. TRAGIS can be used to calculate detailed routes based on user-specified parameters, and replaces the legacy HIGHWAY and INTERLINE routing models.

[2]RADTRAN is the world standard for transportation risk assessment. The code was developed at Sandia National Laboratories. RADTRAN combines user-determined meteorological, demographic, transportation, packaging, and material data with health physics data to calculate the expected radiological consequences and accident risk of transporting radioactive materials.

assessment computer code) [Neuhauser, Kanipe, and Weiner 2000; Chap. 3, 4, and 5] and multiplying the unit risk factors by the appropriate route distances and population densities.

Collective accident dose risks were calculated using the national average truck and rail accident rates from Saricks and Tompkins (1999; Tables 4 and 6). Accident dose risks were calculated by calculating a unit risk factor (that includes severity and release fractions) using RADTRAN 5, and multiplying by the accident rates, distances, and population densities. Traffic fatalities were also taken from Saricks and Tompkins (1999; Tables 4 and 6).

Per-shipment and per-container occupational doses for trans-Atlantic and trans-Pacific shipping were calculated using RADTRAN 5 and using data from Appendix J of the Yucca Mountain Environmental Impact Statement (DOE 2002).

B.3 ASSUMPTIONS

For the incident-free transportation analyses:

- Trucks were assumed to travel only on interstate or U.S. primary highways, and the speed was taken to be 88 km/hour, except during rush hour. Ten percent of urban and suburban truck travel was assumed to be during rush hour. Rush hour speed was assumed to be half of the non-rush hour speed.

- Vehicle densities were assumed to be the standard RADTRAN values: (1) rural: 470 vehicles per hour (vph), (2) suburban: 780 vph, and (3) urban: 2800 vph. Rush hour vehicle densities were assumed to be twice the non-rush hour vehicle density.

- Per the truck stop model of Griego, Smith, and Neuhauser (1996), trucks with onboard restroom facilities were assumed to stop every 525 miles for rest and refueling for an average time of 20 minutes. Two drivers per truck were assumed.

- Truck crew members were assumed to be 3 m from the cargo and their dose regulated at 2 mrem/hr. At stops, one crew member was assumed to stay in the truck at all times.

- Rail speeds were the standard RADTRAN speeds: (1) rural: 64 kph, (2) suburban: 40 kph, and (3) urban: 24 kph.

- External dose rate (TI) at one meter from the surface is assumed to be 1 mrem/hr from a drum or standard waste box, so that adjacent drums would have a total TI of 2 mrem/hr and two layers of adjacent drums, 4 mrem/hr. These are conservative assumptions.

- Crew members aboard transoceanic freighters were assumed to spend two hours per day at a distance between one and 16 m from the containers, and half of the time 30 m from the containers. No credit was taken for shielding.

- The maximum transoceanic distance assumed was 14,400 km, port to port.

For the transportation accident analysis:

- All radioactive material released is assumed to be particulate matter with a settling velocity or 0.01 m/sec.

- The cargo was assumed to include containers containing DU, NU, and LEU. Accident unit risk factors were calculated for DU, NU, and LEU using RADTRAN and using fractions of uranium isotopes shown in Table B.1.

Table B.1. Fractions of uranium isotopes in DU, NU, and LEU

Radionuclide	Fraction in DU	Fraction in NU	Fraction in LEU
^{238}U	0.007	0.992	0.969
^{235}U	0.0025	0.00711	0.03
^{234}U	0.001	0.0009	0.001

DU = depleted uranium.
LEU = low-enriched uranium.
NU = normal uranium.
U = uranium.

- Accident rates were the national average truck and rail accident rates from Saricks and Tompkins (1999; Tables 4 and 6).

- Conditional accident probabilities (severity fractions) and release and aerosol fractions are the same as given in Appendix A.

- It as assumed that 1% of the accidents would result in release of radioactive material, and 99% would not result in any damage to cargo.

- National average meteorological conditions were assumed. Dispersion was calculated using RADTRAN, which incorporates a Gaussian dispersion model. The same model and assumptions were used to calculate airborne concentrations of uranium.

- Fatality rates for truck and rail accidents are from Saricks and Tompkins (1999; Tables 4 and 6).

For transoceanic transportation:

- The longest distance that would be traveled would be 14,400 km, from either the west or east coasts of the United States.

- While the ship is at sea, there is no dose to any member of the public. Only the ship's crew is exposed. An average crew member spends 2 hours per day within 16 m of the cargo, and 22 hours per day at 30 m from the cargo. No shielding is assumed.

B.4 COMPUTER SOFTWARE/MODELS

Unit risk factors were calculated using RADTRAN 5 (Neuhauser, Kanipe, and Weiner 2000). Route segment lengths and population densities were calculated using WebTRAGIS (Johnson and Michelhaugh 2000). Other calculations were done with a Microsoft™ Excel spreadsheet.

B.5 RESULTS

Table B.2 shows the collective dose to the public for the two modal options. As is evident from Table B.2, collective dose is directly proportional to the total distance traveled; the two consolidation options yield the smallest collective dose, and the two east/west options yield collective doses that are not much larger. When rail transportation is used, the collective dose is decreased still further, for two reasons: (1) rural population densities along rail routes are about 50% to 60% of rural population densities along highway routes, and 45% to 75% of any route is rural; and (2) the origin sites that can use rail transportation are those that ship the largest number of containers, thus emphasizing the smaller results for rail shipment. It should be noted that one railcar is one shipment, so the number of cars in a single train that carry uranium does not affect the analysis.

Accident dose risks are several orders of magnitude smaller than incident-free doses. Even if 10% of the accidents were assumed to result in release of radioactive material, the accident dose risks would increase by a factor of ten but would still be negligible compared to the incident-free doses. Accident dose risks for the truck/rail option are somewhat larger than for the truck-only option, because rail accident rates are somewhat larger than heavy truck accident rates.

Table B.2. Public collective dose for uranium transportation

Interim storage alternative	Destination	Public dose and dose risk (person rem)			
		Truck only		Truck and rail	
		Incident-free	Accident	Incident-free	Accident
Centralized storage at a single DOE site	SRS	34.9	0.0036	23.3	0.0137
	Oak Ridge	23.1	0.00198	18.7	0.00775
	PGDP	22.3	0.00165	18.5	0.0154
	PORTS	18.5	0.00123	18.5	0.00477
	INEEL	38.1	0.00379	9.44	0.0233
Centralized storage at a single commercial site	Eastern (Barnwell)	34.6	0.00206	22.1	0.013
	Western (Envirocare)	38.9	0.00414	36.2	0.00341
Partially consolidated storage at two DOE sites	INEEL/PORTS	6.28	8.74E-04	6.85	0.0037
Partially consolidated storage at two commercial sites	Eastern/western	21	0.003	10.1	0.0117
Partially consolidated	By physical form	4.36	7.10E-04	2.15	2.94E-03
	By closest site	4.37	7.07E-04	2.15	2.94E-03

DOE = U.S. Department of Energy.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

The average dose to an individual member of the public was calculated by dividing the doses (and dose risks) shown in Table B.2 by the populations in a mile-wide band along each route. The results are shown in Table B.3.

Table B.3. Average individual public dose (mrem)

Destination	Truck only		Truck and rail	
	Incident-free	Accident	Incident-free	Accident
SRS	6.51E-03	5.41E-06	4.41E-03	2.30E-05
Oak Ridge	5.02E-03	3.13E-06	4.12E-03	1.34E-05
PGDP	4.89E-03	2.51E-06	4.14E-03	2.61E-05
PORTS	4.16E-03	1.86E-06	4.25E-03	7.95E-06
INEEL	5.83E-03	5.65E-06	0.00E+00	3.86E-05
Eastern (Barnwell)	6.58E-03	3.16E-06	4.22E-06	1.99E-05
Western (Envirocare)	5.93E-03	5.99E-06	5.46E-03	5.56E-05
INEEL/PORTS	2.03E-03	1.31E-06	2.28E-03	6.14E-06
Eastern/western	5.87E-02	4.44E-06	2.45E-03	1.60E-05
By physical form	1.59E-03	1.12E-06	8.04E-04	5.03E-06
By closest site	1.63E-03	1.12E-06	8.22E-04	5.04E-06

INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

The average background radiation dose for a person living in the United States is 360 mrem/year. Thus the dose from the proposed shipments of uranium is less than 1/10,000 of the average background dose.

Another comparison that may be made is to calculate possible health effects from these exposures. International Commission on Radiological Protection (ICRP) Publication 60 (ICRP 1991) projects 0.0005 latent cancer fatalities (LCFs) per rem of exposure. The results of applying this factor to the data in Table B.2 are shown in Table B.4.

These projected LCFs are in excess of the potentially fatal cancers projected to occur in the populations along the routes. As Table B.4 shows, less than 1/50 LCF is projected for any alternative.

Table B.5 shows the collective occupational (crew) doses for the various alternatives. These collective doses appear to be quite large, especially since trucks carry a crew of two people. However, truck crew members are considered radiation workers, and both the dose rate and the cumulative dose are limited by regulation. One cannot say at this time how many truck crew members would be involved in these shipping campaigns.

Rail crew members on a train that is in transit (in motion) have no exposure because they are too far from the radioactive material and too well shielded. The collective doses cited in Table B.5 for the truck/rail option include doses to rail classification yard workers.

Table B.4. Potential excess latent cancer fatalities (LCFs)

Interim storage alternative	Destination	Potential excess latent cancer fatalities (total)			
		Truck only		Truck and rail	
		Incident-free	Accident	Incident-free	Accident
Centralized storage at a single DOE site	SRS	0.0175	1.80E-06	0.0117	6.85E-06
	Oak Ridge	0.0116	9.90E-07	0.0094	3.88E-06
	PGDP	0.0112	8.25E-07	0.0093	7.70E-06
	PORTS	0.0093	6.15E-07	0.0093	2.39E-06
	INEEL	0.0191	1.90E-06	0.0047	1.17E-05
Centralized storage at a single commercial site	Eastern (Barnwell)	0.0173	1.03E-06	0.0111	6.50E-06
	Western (Envirocare)	0.0195	2.07E-06	0.0181	1.71E-06
Partially consolidated storage at two DOE sites	INEEL/PORTS	0.0031	4.37E-07	0.0034	1.85E-06
Partially consolidated storage at two commercial sites	Eastern/western	0.0105	1.50E-06	0.0051	5.85E-06
Partially consolidated	By physical form	0.0022	3.55E-07	0.0011	1.47E-06
	By closest site	0.0022	3.54E-07	0.0011	1.47E-06

DOE = U.S. Department of Energy.
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Table B.5. Collective crew dose

Interim storage alternative	Destination	Collective crew dose (person-rem)	
		Truck only	Truck and rail
Centralized storage at a single DOE site	SRS	245	11.1
	Oak Ridge	188	9.73
	PGDP	192	8.71
	PORTS	157	9.38
	INEEL	342	5.33
Centralized storage at a single commercial site	Eastern (Barnwell)	246	11.1
	Western (Envirocare)	346	6.25
Partially consolidated storage at two DOE sites	INEEL/PORTS	48.8	2.07
Partially consolidated storage at two commercial sites	Eastern/western	220	3.34
Partially consolidated	By physical form	36.7	1.84
	By closest site	36.7	1.77

DOE = U.S. Department of Energy.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
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Table B.6 shows projected potential traffic fatalities from truck and rail accidents, which are comparable to projected LCFs. The table also includes airborne concentrations of uranium and uranium compounds. The toxicity threshold for airborne uranium and uranium compound particles is 2 mg/m^3 (Lewis 1993).

Table B.6. Potential traffic fatalities and airborne uranium concentrations

Destination	Traffic fatalities (total)		Airborne concentration of uranium (μg/m^3)
	Truck only	Truck and rail	
SRS	0.00427	0.0078	0.0771
Oak Ridge	0.00374	0.00676	0.0714
PGDP	0.00374	0.0069	0.081
PORTS	0.00357	0.00635	0.0319
INEEL	0.00595	0.0106	0.0797
Eastern (Barnwell)	0.00426	0.0077	0.081
Western (Envirocare)	0.00591	0.0109	0.081
INEEL/PORTS	0.00215	0.0037	0.0306
Eastern/western	0.00256	0.00447	0.081
By physical form	0.0019	0.00309	0.0172
By closest site	0.00183	0.00301	0.017

DOE = U.S. Department of Energy.
INEEL = Idaho National Engineering and Environmental Laboratory.
PGDP = Paducah Gaseous Diffusion Plant.
PORTS = Portsmouth Gaseous Diffusion Plant.
SRS = Savannah River Site.

Radiological impacts of transoceanic transportation were also calculated. While the freighter carrying the uranium is at sea, there is no dose to the public. Projected impacts, based on assumptions in Section B.3, would be:

- the average dose to a crew member would be approximately 1.8 mrem per person per day for each shipment of material, and
- a dock worker loading containers could potentially receive an external dose of 2 mrem.

The total number of shipments needed could not be estimated because this cargo would probably be carried with other cargo, and the amount in each shipment would depend on the rate of arrival at the debarcation port.

B.6 REFERENCES

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